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Radial piston pump for high-pressure fuel generation in  
fuel injection systems of internal combustion engines

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The invention is based on a radial piston pump for high-pressure fuel generation in fuel injection systems of internal combustion engines, in particular in a common rail injection system, having a drive shaft which is mounted in a pump casing and has an eccentric shaft section on which a running roller is mounted, and having preferably a plurality of pistons, which are arranged in a respective cylinder radially with respect to the drive shaft and each have a piston footplate, which makes contact with the circumferential surface of the running roller, at their ends facing the running roller, in accordance with the preamble of claim 1.

A radial piston pump of this type is known, for example, from DE 198 09 315 A1. The piston footplate and the running roller of the known radial piston pump generally consist of case-hardened steel or of heat-treated steel. Over the course of time, however, sliding wear to these components can occur as a result of adhesion, abrasion or surface spalling. This undesirable wear can lead to failure of the radial piston pump and therefore also to failure of the internal combustion engine.

By contrast, the present invention is based on the object of further developing a radial piston pump of the type described in the introduction in such a manner as to increase its reliability.

This object is achieved according to the invention by the characterizing features of claim 1.

The susceptibility of the piston footplate/running roller sliding pairing and of the piston/cylinder

pairing to wear is significantly reduced by virtue of the fact that, for the first time, at least that surface of the piston footplate which is in contact with the circumferential surface of the running roller consists of a wear-resistant material, namely of hard metal, a ceramic material, a cast carbide material or cermet, and/or at least part of the running roller, in particular at least part of the circumferential surface of the running roller, consists of a wear-resistant material, namely of hard metal, a precision-cast material, a cast carbide material, a sintered tool steel or an alloyed nitriding steel and/or the piston consists of a ceramic material. The materials listed have a significantly higher modulus of elasticity compared to the steel materials used hitherto, which results in reduced deformation under load and consequently also in a more uniform surface pressure without significant stress peaks. If ceramic materials are used, in particular their lower weight plays a role, which results in a low mass inertia of the running roller, the piston and the piston footplate.

The running roller and/or the piston footplate may be made entirely from the wear-resistant material, or else these parts consist, as hitherto, of case-hardened steel or heat-treated steel but bear at least one insert made from the wear-resistant material. The use of inserts brings the advantage of a modular structure, i.e. a standardized running roller and a standardized piston footplate can each be provided with inserts made from different material, so that numerous pairing variants can be produced.

On account of the materials properties of the wear-resistant materials used, the following sliding pairings are particularly preferred:

The running roller consists of a heat-treated steel and has inserts of hard metal, such as G20, GC37 or GC20,

and the piston foot disk consists of ceramic, such as  $\text{Si}_3\text{N}_4$  ceramic, of chilled cast iron, such as SoGSH, or of cermet, or it has inserts made from the above-mentioned materials.

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The running roller consists of a precision-cast material, such as GX-210WCr13 H, and the piston foot disk consists of ceramic, such as  $\text{Si}_3\text{N}_4$  ceramic, of hard metal, such as G20, or of cermet, or it has inserts  
10 made from the abovementioned materials.

The running roller consists of a cast carbide material, such as chilled cast iron SoGGH, and the piston foot disk consists of ceramic, such as  $\text{Si}_3\text{N}_4$  ceramic, of hard  
15 metal, such as G20, or of cermet, or it has inserts made from the abovementioned materials.

The running roller consists of sintered tool steel, such as ASP23, or of an alloyed nitriding steel, and  
20 the piston foot disk consists of ceramic, such as  $\text{Si}_3\text{N}_4$  ceramic, of hard metal, such as G20, of cermet or of a cast carbide material, such as SoGGH, or it has inserts made from the abovementioned materials. The alloyed nitriding steel may contain C and/or Cr and/or V and/or  
25 Mo, is gas-nitrided and does not have a compound layer in the region of contact with the piston footplate.

A further measure provides for the surface of the piston footplate and/or of the running roller to have a  
30 surface roughness  $R_z$  of between  $0.15\text{ }\mu\text{m}$  and  $2\text{ }\mu\text{m}$ . More specifically, the ceramic material has a surface roughness  $R_z$  of between  $0.15\text{ }\mu\text{m}$  and  $0.5\text{ }\mu\text{m}$ , the hard metal has a surface roughness  $R_z$  of between  $0.3\text{ }\mu\text{m}$  and  $1.0\text{ }\mu\text{m}$  and the cast carbide material has a surface roughness  
35  $R_z$  of between  $0.5\text{ }\mu\text{m}$  and  $2.0\text{ }\mu\text{m}$ .

It is particularly preferable for the running roller, on its circumferential surface, to have at least one transverse groove extending transversely to the

direction of movement. In addition, the piston footplate may also have at least two grooves which cross one another on its surface facing the running roller. Fuel can accumulate in these grooves, which  
5 each act as a build-up gap, and this fuel, on account of the sliding movement between the circumferential surface of the running roller and the piston footplate, promotes the formation of a hydrodynamic sliding film, which further reduces the wear to the sliding surfaces.

10 Not least, the piston preferably consists of an  $\text{Si}_3\text{N}_4$  ceramic or a  $\text{ZrO}_2$  ceramic, is produced by extrusion and has a porosity of less than 5%, with the surface being infiltrated with  $\text{MoS}_2$ . In particular, the piston is  
15 isostatically extruded and sintered. The result is a very smooth surface with a low coefficient of friction, which is also of benefit to the wear properties.

Exemplary embodiments of the invention are illustrated  
20 in the drawings and explained in more detail in the description which follows. In the drawings:

Fig. 1 shows a cross-sectional illustration of a radial piston pump with a piston footplate and a drive shaft in accordance with a first  
25 embodiment of the invention;

Fig. 2 shows a large cross-sectional illustration of a piston and piston footplate in accordance  
30 with a further embodiment.

Fig. 2a shows an enlarged excerpt from Fig. 2;

Fig. 2b shows a further enlarged excerpt from Fig. 2;

35 Fig. 3 shows a view of the piston footplate from Fig. 2 from below;

Fig. 4 shows a cross-sectional illustration of a piston with piston footplate and a drive shaft in accordance with a further embodiment;

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Fig. 5 shows a cross-sectional illustration of a drive shaft in accordance with a further embodiment;

10 Fig. 6 shows a view on line VI-VI from Fig. 5;

Fig. 7 shows a view on line VII-VII from Fig. 6.

The radial piston pump 1 shown in Fig. 1 is preferably  
15 used to generate the system pressure for the high-pressure reservoir (rail) of a common rail injection system of a compression-ignition internal combustion engine. It comprises a drive shaft 4 mounted in a pump casing 2 with an eccentric shaft section 6, on which a  
20 polygonal running roller 8, which can rotate with respect to the shaft section 6, is mounted. The polygonal running roller 8 has planar flat sections 12 arranged at a circumferential distance from one another along its circumferential surface 10.

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The piston footplate 18 of a piston 16 guided radially with respect to the drive shaft 4 in a cylinder 14 is supported on each of the flat sections 12 of the running roller 8. The piston footplate 18 is preferably  
30 pivotably connected, by means of a spherical bearing 20, to the end of the piston 16 which faces towards the drive shaft 4. The spherical bearing 20 is realized, for example, by the end of the piston being designed as a partial ball 22 which engages in a spherical recess  
35 24 of complementary design in the piston footplate 18. Furthermore, the piston footplate 18, together with the piston 16, is prestressed by a spring 26 onto the associated flat section 12 of the running roller 8. The way in which a radial piston pump 1 of this type

functions is described, for example, in DE 198 02 475 A1 and therefore will not be dealt with in any further detail here.

5 At least that surface 28 of the piston footplate 18 which is in contact with the circumferential surface 10 of the running roller 8 consists of a wear-resistant material, namely of hard metal, a ceramic material, a cast carbide material or cermet. This is preferably  
10 realized by virtue of the fact that the piston footplate 18, on its surface 28 facing towards the running roller 8, has at least one, for example disk-like, insert 30 made from the wear-resistant material. The insert 30 may be positively and/or cohesively  
15 connected to the remaining piston footplate 18, for example by adhesive bonding or soldering. The insert 30 may, as shown in Fig. 1, extend over the entire contact surface 28 of the piston footplate 18 with the running roller 8 or only over part of this contact surface.  
20 Alternatively, it is also possible for the entire piston footplate 18 to be made from the wear-resistant material, so that there is no need for an additional insert 30.

25 If a ceramic material is used for the piston footplate 18, it preferably contains silicon nitride  $\text{Si}_3\text{N}_4$ . Hard metals may, for example, consists of G20, GC37 or GC20, while the cast carbide material may contain a chilled cast iron material, in particular GGH or SoGGH.

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Furthermore, the piston 16 itself may be made from wear-resistant material, for example from an  $\text{Si}_3\text{N}_4$  ceramic or a  $\text{ZrO}_2$  ceramic. The piston 16 may be produced by extrusion and have a porosity of less than  
35 5%, in which case the surface is infiltrated with  $\text{MoS}_2$ . Alternatively, the piston 16 may also be isostatically pressed and sintered.

Not least, it is also the case that at least part of the running roller 8, in particular the flat sections 12, consists of a wear-resistant material, namely of hard metal, a precision-cast material, a cast carbide material, a sintered tool steel or an alloyed nitriding steel.

As in the case of the piston footplate 18, this is preferably realized by virtue of the fact that the flat sections 12 are each provided with an insert 32 of the wear-resistant material, as shown in Fig. 1. An insert 32 of this type is in each case held positively and/or cohesively in a recess 34 of complementary shape in the flat section 12, for example by adhesive bonding or soldering. Alternatively, the entire running roller 8 may consist of the wear-resistant material.

If hard metal is used for the inserts 32 or for the running roller 8 itself, a particularly wear-resistant hard metal with a Vickers hardness of at least HV 1100 and a fracture toughness  $K_{IC} \geq 10 \text{ MPa/m}^{3/2}$  with binder contents of 12 to 20% is suitable, particularly preferably G20, GC37 or GC20. In particular hard metals which have low adhesion coefficients are used here. A suitable precision-cast material is formed, for example, by GX-210WCr13 H, while a suitable cast carbide material is locally remelted, carbide SoGGH (gradient material). A suitable sintered tool steel is ASP23. A nitriding steel which has been specially alloyed with Cr and/or Mo and/or V and/or C by nitriding or gas-nitriding is used for a variant with a gradient material. The basic elements and the process parameters used in the nitriding lead to deep diffusion with hardnesses of HV 750 to 850 combined, at the same time, with a higher strength of the base material. The compound layer which is formed is removed by grinding for functional reasons. The surfaces of the piston footplate 18 and of the running roller 8 preferably have a surface roughness  $R_z$  of between  $0.15 \mu\text{m}$  and

2  $\mu\text{m}$ , depending on the materials used, on the sliding surfaces. The lower limit applies to ceramic, in particular a range from 0.15  $\mu\text{m}$  to 0.5  $\mu\text{m}$ , while the upper limit applies to metals such as SoGGH or ASP23. A  
5 surface roughness  $R_z$  of between 0.3  $\mu\text{m}$  and 1  $\mu\text{m}$  is provided for hard metal.

The table below lists preferred material pairings for the piston footplate 18, on the one hand, and the  
10 running roller 8, on the other hand. If inserts are used both in the running roller 8 and in the piston footplate 18, any desired combinations of material pairings are possible with the support bodies in each case unchanged. In particular, with the pairings in the  
15 table in which the running roller 8 preferably consists entirely of the wear-resistant material ("solid material"), it is alternatively also possible to use inserts 32 made from the corresponding material in the region of the flat sections 12, as has already been  
20 demonstrated in Fig. 1. The running roller 8 as support body for the inserts 32 may then consist of a different material, for example 50Cr4, 42CrV4 or 16MnCr5. The exemplary embodiment in the third line of the table plays a particular role. In this case, a carbide zone  
25 is in each case formed in the region of the flat sections 12 of the running roller 8 consisting of a cast steel material and illustrated separately in Fig. 5. This carbide zone is produced either by a targeted solidification rate during casting of the running  
30 roller 8 or by remelting and then preferably forms the gradient material SoGGH. Consequently, the result is a running roller 8 in which a carbide zone 33 has been formed in the region of the surface sections 12, while the remaining zones and regions of the running roller 8  
35 consist of cast steel with unchanged properties.

Running roller	Piston foot disk
Inserts of hard metal, e.g. G20, GC37, GC20	Solid material or inserts comprising a) ceramic, e.g. $\text{Si}_3\text{N}_4$ ceramic b) chilled cast iron, e.g. SoGGH c) Cermet
Solid precision-cast material, e.g. GX- 210WCr13 H	Solid material or inserts comprising a) ceramic, e.g. $\text{Si}_3\text{N}_4$ ceramic b) hard metal, e.g. G20 c) Cermet
Solid cast carbide material, e.g. chilled cast iron SoGGH	Solid material or inserts comprising a) ceramic, e.g. $\text{Si}_3\text{N}_4$ ceramic b) hard metal, e.g. G20 c) Cermet
Solid material - comprising sintered tool steel, e.g. ASP23, - comprising C, Cr, Mo, V-alloyed nitriding steel	Solid material or inserts comprising a) ceramic, e.g. $\text{Si}_3\text{N}_4$ ceramic b) hard metal, e.g. G20 c) Cermet d) cast carbide material, e.g. SoGGH

Table: Preferred material pairings

In each case one or more transverse grooves 36 may be formed in the region of the flat sections 12 of the running roller 8, as can be seen most clearly from Fig. 6. As can be seen from Fig. 7, the transverse groove 36 is arranged in the center of a depression 29, forming a groove run-out, in the flat section 12. The depression 29 is formed by two planes arranged at an angle with respect to the flat section 12, with the transverse groove 36 at their intersection line. The depression angle  $\gamma$  of the depression 29 is, for example, less than 15 degrees. The transition from the depression 29 to the flat section 12 is rounded with a radius  $R_4$  of preferably less than or equal to 1 mm. The radius  $R_4$  is

produced for example by grinding. Fuel can accumulate in this transverse groove 36 or depression 29, which acts as a build-up gap, which fuel, on account of the sliding velocity between the flat sections 12 of the running roller 8 and the piston footplate 18, promotes the formation of a hydrodynamic sliding film, thereby reducing the wear to the sliding surfaces.

In the embodiments shown in Fig. 2 to Fig. 4, those parts which remain the same as and have the same action as in the example shown in Fig. 1 are denoted by the same reference designations. By contrast, in the example shown in Fig. 2, the piston footplate 18 is held on the associated piston 16 by a plate holder 38. The piston footplate 18, on its surface facing the piston 16, has a circular recess 40, in which the spherically shaped end 42 of the piston 16 engages, coming into contact with the base of the recess 40. The plate holder 38 is locked on the piston 16 by means of a circlip 46 engaging in a groove 44 in the piston 16. A circular insert 30 made from one of the wear-resistant materials described above is held in a recess 48 of complementary shape in the piston footplate 18, for example by cohesive bonding, in particular by soldering. As can be seen from Fig. 2a, the insert 30 is provided at the edge side, on its surface 31 facing the running roller 8, with an angled run-out 35, the run-out angle  $\alpha$  amounting to approximately 15 degrees. Furthermore, the transition between this surface 31 and the run-out 35 is rounded with a radius  $R_2$  of approx. 2 mm. The transition between the run-out 35 and the edge surface 37 of the insert 30 is also rounded by means of a radius  $R_1$  of less than or equal to 1 mm.

Similarly to the flat sections 12 of the running roller 8, the inserts 30 of the piston footplate 18 preferably have at least two grooves 50 which cross one another, as can be seen most clearly from Fig. 3. On account of the grooves 50 being arranged so as to cross one

another, there is a high probability that, with regard to the piston footplate 18 which can rotate with respect to the plate holder 38, one of the grooves 50 will be oriented transversely with respect to the direction of movement, in order to promote the formation of a hydrodynamic lubricating film. The grooves 50 are preferably produced by pressing. This results in a lower notch effect compared to chip-forming processes, since the material fibers are not severed. As can be seen from Fig. 2b, the grooves 50 are each arranged in the center of a depression 39, forming a groove run-out, in the surface 31. The depression is formed by two planes arranged at an angle with respect to the surface 31, with the respective groove 50 located at the intersection line of these planes. The depression angle  $\beta$  of the depression 39 is, for example 5 degrees. The transition between the depression 39 and the surface 31 is rounded with a radius  $R_3$  of preferably less than or equal to 1 mm.

In the exemplary embodiment shown in Fig. 4, the piston footplate 18 consists entirely of one of the wear-resistant materials mentioned above and is fitted into the passage hole 52 in an annular bush 54 which consists of steel. The connection between the annular bush 54 and the piston footplate 18 is preferably produced by soldering. Of course, there are also other conceivable options for arranging wear-resistant material on the mutually associated sliding surfaces 12, 28 of the running roller 8 and piston footplate 18.